Simultaneous Capturing of the Effective Mass and Fermi Velocity of Relativistic Fermions in Quantum Matters by *q*-EELS

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Quantum matters boast relativistic fermions by the iconic conical spectrum of $\hbar v_F q$ near the Fermi level ($\hbar$, reduced Planck's constant; v_F, Fermi velocity; q, momentum). A plethora of exotic phenomena that have no classical counterparts emerge in the matters and their profound understanding is tied to the capturing of the fundamental parameters of the effective mass (m^*) and v_F of these fermions [1]. Customarily, m^* is to be resolved using low-temperature, high-field quantum magneto-oscillations and v_F is to be derived by Landau or angle-resolved photoemission spectroscopy [1]. The methodology for a simultaneous gauge of the two parameters has not been reported, while highly demanded. Here, we demonstrate that q-dependent electron energy loss spectroscopy (q-EELS) is a robust probe for m^* and simultaneously v_F using the plasmon dispersion of designated fermions near the Fermi level. The plasmon dispersion of free carriers quadratically scales with v_F and the plasmon excitation energy is a function of m^* [2]. The thorough investigation of plasmon dispersions can readily devise characteristic m^* and v_F. Fig. 1 shows the q-EELS map for two-branch of plasmon dispersions in a quantum semimetal of our choice, with the black (gray) arrow indicating the relativistic electrons' (massive holes') and the white arrow otherwise pinpointing a dipole-forbidden interband transition. Solving the plasmon dispersion equation for the observed plasmon of the relativistic electrons (black dots, Fig. 1), we establish the m^* of 0.28 m_0 (the rest mass of electron) and v_F of ~1.6×10^6 m s^{-1}. Surprisingly, the v_F closely mimics that of pristine graphene, with ~1.5×10^6 m s^{-1} (i.e., ~0.005 c; c, the speed of light). With decreasing temperatures to 100 K, the q-EELS experiments unveil that the relativistic electrons in the semimetal become lighter and faster, advantageous for conveying relativistic quantum phenomena. The grand detail of our q-EELS methodology and its applications in quantum materials are to be discussed in this workshop.

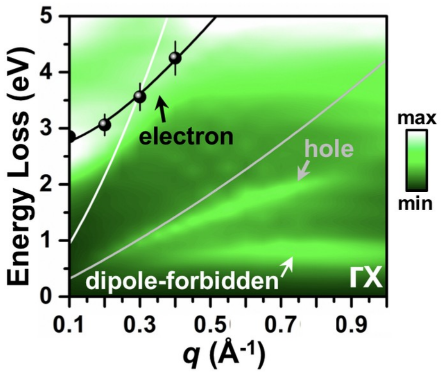

FIG. 1. The q-EELS map of a quantum semimetal. Black (gray) arrow, the plasmon dispersion of relativistic electrons (massive holes). White arrow, the dipole-forbidden interband transition. Black curve, the calculated plasmon dispersion based on the resolved m^* and V_F. White (gray) curve, the single-particle continuum of the relativistic electrons (massive holes).

References:

[1] M. Kang *et al.*, *Nat. Mater.* 19, 163 (2020).
[2] P. M. Platzman and P. A. Wolff, *Waves and Interactions in Solid State Plasmas* (Academy Press, New York and London, 1973).